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EMERGENCE PATTERNS OF FALL AND WINTER STONEFLIES (PLECOPTERA: FILIPALPIA) IN NORTHWESTERN SOUTH CAROLINA[1]

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Abstract.—Fall and winter stoneflies were collected from November 23, 1976 through April 12, 1977 from a mountain and an upper piedmont stream in South Carolina to determine the species composition, emergence patterns, and seasonal distribution of the adults.

Allocapnia aurora Ricker demonstrated early seasonal emergence and appeared only at the upper piedmont creek. *Allocapnia recta* (Claassen) demonstrated early seasonal emergence at both creeks. *Leuctra ferruginea* (Walker) demonstrated a continuous emergence at the upper piedmont creek, but depicted the late seasonal pattern at the mountain creek. *Taeniopteryx maura* (Pictet) demonstrated mid-seasonal emergence at both localities. Although the emergence periods did overlap, peak emergence for each species was separated clearly at both creeks.

Studies of Plecoptera in South Carolina have been limited to a report of one species by Needham and Claassen (1925) and a list of 52 species in 17 genera by McCaskill and Prins (1968) and McCaskill (1967, 1973). Investigations of emergence patterns of fall and winter stoneflies have occurred only in more northern latitudes.

The objectives of this study were to determine the species composition, emergence patterns, and seasonal distribution of fall and winter stoneflies from the upper piedmont and mountain regions of South Carolina. Also, an equally important objective was to examine influence of air and water temperature on emergence.

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Description of the Study Area

Limber Pole Creek

Limber Pole Creek is located approximately 14 km north of Salem in Oconee County, South Carolina. It is a relatively small headwater mountain creek at an altitude of about 395 m above sea level. Limber Pole Creek flows in a southeasterly direction until its confluence with Howard Creek, which eventually empties into Lake Jocassee.

The substrate of the creek varies from silt and sand with large boulders to sheer rock bottom with some silt and sand deposits. The large boulders in the stream are covered with algae and mosses. The creek also contains large deposits of logs, limbs, and leaves. The terrain can generally be described as mountainous with steep slopes. The surrounding vegetation consists of hickory (*Carya*), holly (*Ilex*), oak (*Quercus*), pine (*Pinus*), mountain laurel (*Kalmia*), and rhododendron (*Rhododendron*).

Limber Pole Creek supports a great diversity of animal life. Fish are abundant, as are populations of Plecoptera, Ephemeroptera, Diptera, Trichoptera, and other benthic insects.

The trapping site was located 0.8 km from the mouth in a relatively shallow area (3 to 15 cm deep). Discharge ranged from near 0 to 24 cms, with an average velocity of 1.5 m/sec.

Wildcat Creek

Wildcat Creek is located in Pickens County, South Carolina, 9 km northwest of Clemson. It is situated in the Issaqueena Forest, part of the Clemson University Experimental Forest. The creek has been subjected to little agricultural pollution, although the area around Issaqueena Forest has been extensively farmed. Logging occurs periodically within the forest, and an old logging road yielded access to the study site.

Wildcat Creek varies in altitude from 213 to 286 m above sea level. It is a small piedmont stream with southwesterly flow and a total length of 2.5 km. Wildcat Creek enters Six Mile Creek, which then empties into Lake Issaqueena. Discharge under normal conditions ranged from near 0 to 19 cms, with an average velocity of around 1.2 m/sec.

The substrate of Wildcat Creek includes silt, fine to coarse sand, boulders covered with mosses and algae, and granite ledges. Large logs, limbs, and deposits of detritus were common within the stream. Microhabitats included pools, riffles, and moderate waterfalls. Small unknown fishes were observed within the creek as well as large populations of Plecoptera, Ephemeroptera, Diptera, Odonata, Trichoptera, and Coleoptera.

The terrain is typically piedmont with rolling hills. The vegetation consists of pine, redbud (*Cercis*), holly, oak, and hickory. Mountain laurel lined the creek as did a variety of other shrubs and vines.

Fig. 1. Photograph of Tent Trap at Limber Pole Creek.

The study site was 1.15 km above the mouth in riffle areas of the creek which were about 20 cm deep.

Methods

Stoneflies from the two study sites were collected from November 23, 1976 through April 12, 1977. Collections at Wildcat Creek were made 4 to 6 times per week, while those at Limber Pole Creek were made twice per week.

On each collection date, the following methods were employed: (1) Removal of adults and exuviae from the tent traps at the study sites; (2) examination of rocks, logs, and banks for adult stoneflies; and (3) collections of adults with a Tropics® net on bank vegetation along both sides of the creek. All adults were counted in the field and the number recorded. The specimens were preserved in 70% ETOH.

Two tent traps were erected at Wildcat Creek. The traps were constructed from two large cotton and polyester sheets and were approximately 5.5 m long and 1.3 m wide. Trap no. 1 was tied on top at the center and at both ends to stakes 1.3 m high which had been driven into the creek bed. The trap was anchored by ropes tied to rocks at five places along its perimeter. One lengthwise edge overlapped the stream margin by about 20 cm to retain any adults that emerged after climbing onto the bank. Trap no. 2 was suspended over two large tree limbs overhanging the creek, and attached to

rocks within the creek. A similar tent trap was erected at Limber Pole Creek and was anchored in the same manner as trap no. 1 at Wildcat Creek (Fig. 1).

Boulders, sand, and leaves were added under all tent traps whenever collections were made. The added material increased the amount of nymphal habitat and increased the stability of the traps.

The tent traps appeared to retain adequately the stoneflies as long as collections were made frequently. Spiders and webs were destroyed on each visit to reduce predation on the stoneflies. Heavy rains and high winds occasionally jarred the stoneflies into the water. The short life span of the stoneflies also necessitated frequent collections, as the dead adults that fell from the trap into the creek were lost.

Nymphal collections were made approximately once per month in both creeks. These samples were made to determine if the adult collections were giving a thorough representation of the species present in the creeks.

The rearing of fully developed nymphs was conducted in the field in order to associate nymphs and adults. Only one nymph was placed in each rearing container, and after emergence both adult and exuviae were preserved. The rearing container used in this study was designed by Müller-Liebenau (1969) and simplified by Peters (1969). It consisted of a 250 cc plastic cup with two net-covered openings in the lower portion.

Water and air temperature at the time of collection were measured. Dissolved oxygen, pH, turbidity, alkalinity ($CaCO_3$), nitrates (NO_3), ammonia (NH_3), and total phosphates were measured with a Hach Kit®. Daily maximum and minimum air temperatures, maximum and minimum humidity, and precipitation were provided by Kish (1977, personal communication).

Results and Discussion

Species Composition

Four species of fall and winter stoneflies were collected from Wildcat Creek, and three of these species were collected also from Limber Pole Creek (Table 1). *Allocapnia recta* (Claassen) was collected only at Wildcat Creek. *Allocapnia aurora* Ricker was collected from both creeks in large numbers. *Leuctra ferruginea* (Walker) was reported for the first time in South Carolina, and *Taeniopteryx maura* (Pictet) was reported as a new record for Oconee County.

Approximately 90% of the specimens were collected in the tent traps. The remainder of the specimens was collected by sweeping and searches of the substrate. *Taeniopteryx maura* was the only species not collected by sweeping.

Emergence Behavior

Emergence behavior of the various species was observed. When ready to emerge, the nymphs climbed out of the water and attached to the substrate

Table 1. Adult fall and winter stoneflies collected at Wildcat Creek and Limber Pole Creek, South Carolina, emergence periods and number of specimens by sex.

Species	Locality	Emergence Period 1976–1977	Number of Specimens				
			Sex				
			Male	%	Female	%	Total
Allocapnia recta (Claassen)	Limber Pole Creek	—					
	Wildcat Creek	Nov. 23–Mar. 19	287	56	226	44	513
Allocapnia aurora Ricker	Limber Pole Creek	Nov. 24–Mar. 20	348	61	224	39	572
	Wildcat Creek	Nov. 23–Feb. 19	935	55	749	45	1684
Leuctra ferruginea (Walker)	Limber Pole Creek	Nov. 24–Mar. 12	81	47	90	53	171
	Wildcat Creek	Nov. 23–Mar. 6	45	66	23	34	68
Taeniopteryx maura (Pictet)	Limber Pole Creek	Jan. 2–Mar. 23	28	44	36	56	64
	Wildcat Creek	Jan. 30–Mar. 26	4	50	4	50	8

with their claws. The exoskeleton split longitudinally along a dorsal suture and the teneral adult emerged.

Exuviae of *A. recta* and *A. aurora* were found 5 to 8 cm above the water surface on the tents, while exuviae of *L. ferruginea* were found 30 to 40 cm above the water on the side of the trap. Most nymphs of *T. maura* climbed to the top of the trap before emerging.

The teneral adults usually required about 2 hours to reach maturity. Adults of *Allocapnia* and *Leuctra* folded their wings over their back while in the teneral phase, but the teneral adults of *Taeniopteryx* lifted their wings into a tentlike position similar to that of mayflies and changed the wings to the usual position when maturation was completed.

Seasonal Emergence

The fall and winter stoneflies are unique because of their emergence habits during the cold months of the year. However, detailed studies of their emergence have been rare and the present study is the first to examine emergence in the South.

Aquatic insects exhibit various types of emergence patterns that are correlated directly to the life cycle of a particular insect. Corbet (1964) recognized four basic temporal emergence patterns: Continuous, rhythmic, sporadic, and seasonal. Continuous emergence, with relatively little fluctuation in rate, is considered to be the simplest condition from which other emergence patterns are derived. Rhythmic emergence shows cyclical fluctuation in rate which is apparently based on lunar phases. Sporadic emergence is characterized by short bursts of emergence separated by irregular intervals of a few days during which no emergence occurs. In seasonal emergence, a species emerges primarily during one of the four seasons of the year. Corbet also divided seasonal emergence into early, mid, and late seasonal categories. The time at which peak emergence occurs determines the subcategory to which a species belongs.

Allocapnia aurora and *A. recta* (Figs. 2A, 2B, 3A) apparently illustrated early seasonal emergence. This pattern is characterized by a rapid increase in numbers of specimens emerging to a peak in the late fall or early winter, followed by a slow decline. Previous studies by Carlson (personal communication) at Wildcat Creek indicated that while emergence was initiated before November 23, the observed pattern would not be affected greatly.

Allocapnia recta and *A. aurora* emerged in largest numbers in December, with the midpoint of emergence for *A. recta* occurring 2 to 3 weeks before that of *A. aurora*. *Allocapnia recta* completed emergence approximately one month before *A. aurora*. *Allocapnia aurora* had similar emergence periods and patterns at both creeks.

Known distributional records for *A. aurora* include USA: Alabama, Georgia, Maryland, North Carolina, South Carolina, Tennessee, and Virginia.

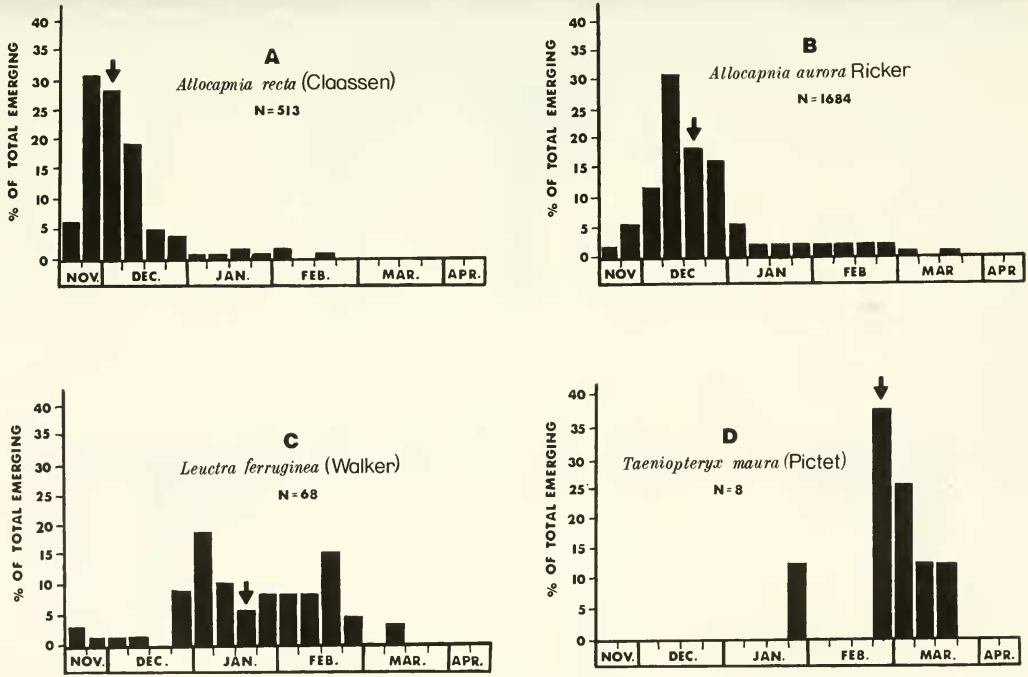

Fig. 2. Emergence patterns of the four species of stoneflies collected from Wildcat Creek. The midpoint of emergence is indicated by the arrow. N indicates total number collected.

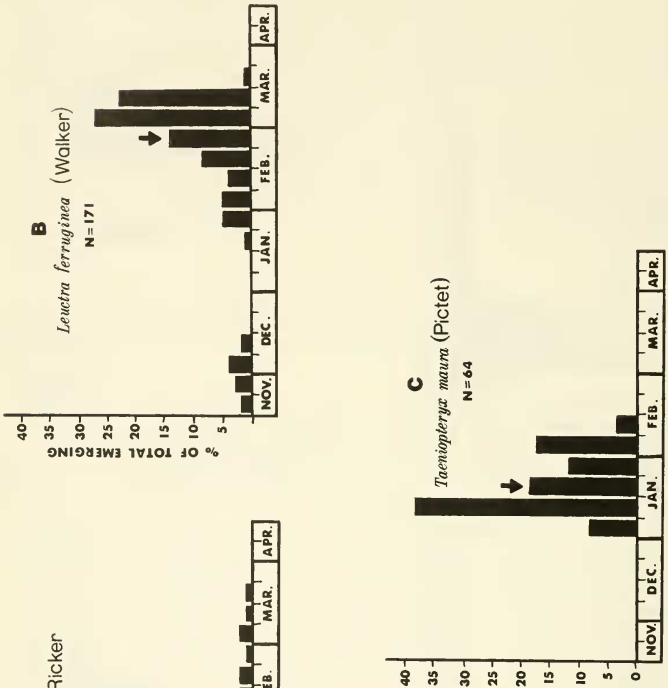

Fig. 3. Emergence patterns of the three species of stoneflies collected from Limber Pole Creek. The midpoint of emergence is indicated by the arrow. N indicates total number collected.

Allocapnia recta has been reported from Canada: Nova Scotia, Ontario, and Quebec; USA: Alabama, Connecticut, District of Columbia, Georgia, Illinois, Indiana, Kentucky, Maine, Maryland, Massachusetts, Mississippi, New Hampshire, New York, North Carolina, Pennsylvania, South Carolina, Tennessee, Vermont, Virginia, and West Virginia.

Leuctra ferruginea at Wildcat Creek (Fig. 2C) exhibited a pattern which was most similar to the continuous seasonal emergence pattern. However, there were small increases in emergence in late January and late February. The pattern of *L. ferruginea* at Limber Pole Creek (Fig. 3B) was apparently the late seasonal type. Emergence probably began prior to November 23, 1976, but no specimens of *L. ferruginea* were collected from mid-December to mid-January. However, during this period without emergence, there were extremely high winds; and the tent trap was stolen on one occasion and collapsed on another. Therefore it is possible that some adults emerged but were not collected, although this is unlikely because collections of *Taeniopteryx maura* were not affected.

Leuctra ferruginea had a slightly longer emergence period at Limber Pole Creek than at Wildcat Creek, with the midpoint of emergence occurring the last week in February at Limber Pole Creek, five weeks earlier than at Wildcat Creek. The species showed peak emergence at Limber Pole Creek the beginning of March but showed no peak emergence at Wildcat Creek. No specimens were collected in the traps after March 6 at Wildcat Creek, although earlier collections by Carlson (personal communication) have shown the species to be present as late as June 6.

Illies (1966) and Zwick (1973) record the distribution of *L. ferruginea* as Canada: Nova Scotia and Quebec; USA: Maine south to Florida, west to Minnesota and Illinois.

Taeniopteryx maura illustrated the mid-seasonal pattern (Figs. 2D, 3C). In this pattern the number of species emerging increases to a peak in mid-winter then decreases slowly.

Taeniopteryx maura began emerging January 2, 1977 at Limber Pole Creek but was not collected at Wildcat Creek until January 30, 1977. However, *T. maura* completed emergence at both creeks during the third week of March. It emerged in greatest numbers at Limber Pole Creek in January, whereas the few specimens from Wildcat Creek were taken primarily in late February and March.

There were only eight specimens of *T. maura* collected at Wildcat Creek. This species was collected in the traps only after a heavy rainfall. Catastrophic drift may have caused displacement of the nymphs to the study site from upstream. Further studies should be made to determine if catastrophic drift was responsible for the appearance of *T. maura* at this study site. If catastrophic drift was responsible, the emergence pattern may be different.

Taeniopteryx maura has been reported from Canada: New Brunswick,

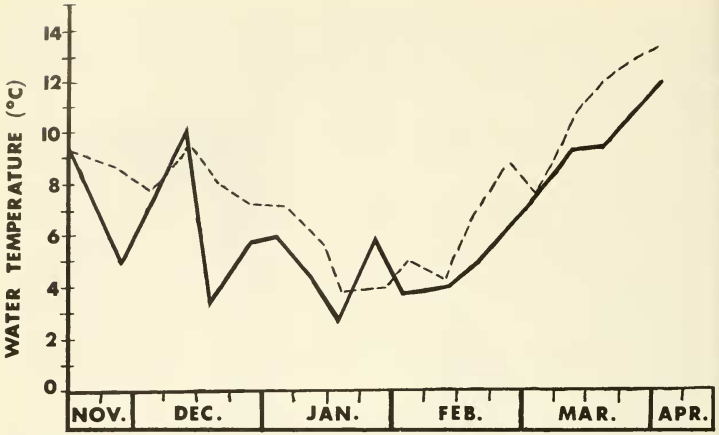

Fig. 4. Average weekly water temperature at the Limber Pole Creek study site (solid line) and Wildcat Creek study site (dotted line).

Nova Scotia, and Ontario; USA: Alabama, Arkansas, Connecticut, Georgia, Indiana, Kentucky, Maryland, Minnesota, Mississippi, New York, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee, Virginia, and West Virginia according to Illies (1966) and Zwick (1973).

There was temporal separation of peak emergence in all species at both creeks. *Allocapnia recta* demonstrated peak emergence at Wildcat Creek the last week in November and the first week in December. *Allocapnia aurora* followed with peak emergence during mid-December at both creeks. At Limber Pole Creek, *T. maura* showed peak emergence in January and *L. ferruginea* in late February and early March. *Taeniopteryx maura* showed peak emergence in February at Wildcat Creek, while *L. ferruginea* emerged at a steady rate from November through March.

Environmental Factors

Temperature and photoperiod acting independently or together are seasonally variable factors which most likely are responsible for differences in the duration of emergence from one habitat to another. There was a sharp decrease in water temperature at Wildcat Creek from early January through mid-February, which was accompanied by a distinct decrease in emergence (Fig. 4). *Allocapnia aurora* showed a decrease in emergence during that period of approximately 12% (Fig. 2B). Limber Pole Creek showed low water temperatures during the third week in December, when the emergence

of *A. aurora* decreased by 25% (Fig. 3A), and the third week in January when the emergence of this species declined by 6%, and the occurrence of *T. maura* decreased by 20% (Fig. 3C). Generally water temperatures of 7 to 10°C caused maximum emergence during the late fall and winter, as was shown by *A. aurora* at both creeks during November and December (Figs. 2B, 3A).

The fall and winter stoneflies in this study emerged at water temperatures as low as 2.5°C, although the number of specimens was sharply reduced (Fig. 3). Khoo (1964) showed that a rise in water temperature stimulates the emergence of stoneflies, and this fact was demonstrated by all species in this study.

The extremely cold weather and unusually heavy snowfall during the 1976–77 winter must be considered when interpreting the data from this study. Air temperatures during the month of January were the lowest recorded since 1880 and were accompanied by decreases in water temperature to 2.5°C. The unusual weather conditions may have caused atypical emergence behavior.

There were no major differences in the water quality parameters measured at Wildcat Creek and Limber Pole Creek. Both streams had slightly acidic water of high quality that indicated minimal organic pollution.

The emergence periods of species found at both biogeographical areas in this study showed no major differences. The similarity of emergence reflects the similarity in altitude, temperature, water quality, and proximity of the two sites. However, differences in emergence based on biogeographical region may be considerable because of the wide range of the species involved in this study. *Allocapnia recta* exhibited maximum abundance at Wildcat Creek during the last week of November and first two weeks of December. Near Oakwood, Illinois, this species exhibits maximum abundance during the last week in January and the first week in February (Frison, 1935). Therefore the emergence of *A. recta* occurs later in the northern latitudes than it does in the more southerly latitudes, implying that temperature or other environmental factors strongly influence emergence.

Acknowledgments

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Literature Cited

Corbet, P. S. 1964. Temporal patterns of emergence in aquatic insects. Can. Entomol. 96:264–279.

Frison, T. H. 1935. The stoneflies, or Plecoptera of Illinois. Ill. Nat. Hist. Surv. Bull. 29:281–471.

Illies, J. 1966. Katalog der rezenten Plecoptera. Das Tierreich 82:1–632.
Khoo, S. J. 1964. Studies in the biology of *Capnia bifrons* (Newman) and notes on the diapause in the nymphs of this species. Gewasser und Abwasser. 34/35:23–30.
Kish, A. J. 1977. Clemson University and South Carolina agricultural experiment stations—1976 climatological data. Agric. Weather Res. Ser. No. 49, 32 pp.
McCaskill, V. H. 1967. A survey of the stoneflies (Order Plecoptera) of northwestern South Carolina. Masters Thesis, Clemson University, Clemson, S.C. 29631.
———. 1973. The stoneflies (Order Plecoptera) of South Carolina. Ph.D. dissertation, Clemson University, Clemson, S.C. 29631.
McCaskill, V. H. and R. Prins. 1968. Stoneflies of northwestern South Carolina. J. Elisha Mitchell Soc. 84:448–453.
Müller-Liebenau, I. 1969. Revision der Eüropa ischen arten der gattung *Baetis* Leach, 1815 (Insecta, Ephemeroptera). Limnologiochi Scherift en reiche. 48–49, 214 pp.
Needham, J. G. and P. W. Claassen. 1925. A monograph of the Plecoptera or stoneflies of America north of Mexico. Publ., Thomas Say Found., Entomol. Soc. Am. 2, 397 pp.
Peters, W. 1969. Rearing Ephemeroptera. Symposium on aquatic insects. Bull. Entomol. Soc. Am. 15:224.
Zwick, P. 1973. Plecoptera phylogenetisches system und katalog. Das Tierreich. 92:1–465.